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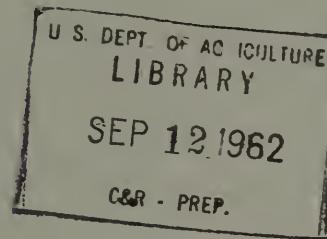
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DOUGLAS-FIR CONE AND SEED INSECT RESEARCH

Progress Report, 1959

By

Thomas W. Koerber, Entomologist



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U. S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE
PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION

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U. S. DEPARTMENT OF AGRICULTURE - FOREST SERVICE
PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION
Division of Forest Insect Research

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SUMMARY

This is a report of studies on insects affecting seed production on Douglas-fir trees. The principal objectives of the studies were to determine the identity and role of the various species of insects found in or on Douglas-fir cones, and to gather data on the seasonal histories of those insects which are already known to destroy the seeds.

Among the insects collected were 14 species which have not previously been associated with Douglas-fir cones. Two of these previously unreported species were found damaging the seeds. One of the newly discovered pests, Leptoglossus occidentalis Heid. (Hemiptera, Coreidae) was found to feed upon seeds of 12 western conifers under laboratory conditions. This insect damages the seed by piercing the seed coat with its needle-like mouthparts, dissolving part of the endosperm by means of a salivary secretion and sucking out the dissolved material. The damaged endosperm becomes greatly shrunken and spongy in appearance.

Seasonal history studies produced useful information on the attack periods of the insects already recognized as serious pests of Douglas-fir cones. Barbara colfaxiana (Kearf.) attacked the cones over a long period from the time the cone buds opened (April 10, approximately) until late in May. The larvae of B. colfaxiana developed slowly at first and did not begin to damage the seeds until early June. Most of the damage was caused by late-instar larvae during June and early July.

Fragmentary data indicate that Dioryctria abietella (D. & S.) probably attacked the cones in early July. In any event most of the damage from Dioryctria larvae occurred during July and early August. Some of the larvae which matured in August pupated and transformed to adults immediately while others delayed transformation until the following spring.

Oviposition by Megastigmus spermotrophus Wachtl was first observed on May 9. Large larvae were found in the seeds by July 21. The Megastigmus population evidently suffered heavy mortality due to the destruction of seeds by lepidopterous larvae.

Contarinia sp. deposits eggs between the cone scales during the short period when the cone scales are open for pollination. The galls formed by Contarinia larvae were easily found by June 6. Here again it appears that feeding by lepidopterous larvae caused considerable mortality in the Contarinia population.

A series of experiments was conducted in which cone-bearing Douglas-fir branches were covered with fine mesh screening to exclude insects. About half of the cones which had been covered were exposed to insect attack for a short time during the oviposition period of insects known to damage the cones. Comparisons of the amount of damage and species of insects which developed were made between three classes of cones: those never exposed, those exposed for a stated period, and those never protected.

Data were obtained on the attack periods of the various insects, on the relative amounts of damage caused by each species, and on the intensity of interspecific competition. The data obtained about the attack periods of the insects corroborates the information obtained by cone dissections.

Larvae of Barbara colfaxiana caused more damage than any of the other species present. They were responsible for the destruction of slightly more than 50 percent of the seed crop. Larvae of Dioryctria abietella destroyed about half as much seed as Barbara larvae, but it appears that Dioryctria would be a more serious pest in the absence of Barbara. The remaining insects, Megastigmus spermotrophus, Contarinia sp., and Leptoglossus occidentalis each destroyed less than 5 percent of the seed crop. However, all of these species gave evidence of being potentially much more destructive.

Interspecific competition appears to be an important factor in determining the relative amounts of damage caused by the various species. Lepidopterous larvae destroy many seeds which are infested by Megastigmus and Contarinia larvae. It appears that in the absence of lepidopterous larvae the other insects could cause more damage and might quickly build up to population levels far higher than are generally encountered.

INTRODUCTION

The research reported here is a segment of a continuing study started in 1957 of insects attacking the cones and seeds of Douglas-fir. This report covers the work started or in progress during the Calendar Year 1959. Research done during 1957 and 1958 is reported in an earlier progress report¹ and the general outlines and objectives of the work are presented in a problem analysis.²

The objective of the research reported here was to provide data on the relative importance of the various species of insects attacking the cones along with information on their habits and seasonal history. Particular emphasis was placed on gathering seasonal history data because of its basic importance in the planning of further research. The information obtained in this study, together with the findings of other researchers, will be used as a plan for the long-term conduct of research on Douglas-fir cone insects and eventually in the formulation of control practices.

Most of the field work reported here was done in the vicinity of Orleans in Humboldt County, on the Six Rivers National Forest. There some of the facilities of the Orleans Ranger Station were made available to project personnel, and a field laboratory has been established.

Cooperation from several other sources has helped to facilitate progress in the research. The Department of Entomology and Parasitology, University of California, made available insectary and coldroom facilities at Berkeley for certain phases of the work. C. J. DeMars assisted in gathering the cone samples. The insects reared from the cone samples were identified by specialists in the Insect Identification and Parasite Introduction Research Branch, Entomology Research Division, Agricultural Research Service, U. S. Department of Agriculture, Washington, D. C.

COLLECTION AND REARING OF INSECTS ASSOCIATED WITH DOUGLAS-FIR CONES

IDENTITY OF INSECTS

Insects associated with or found in Douglas-fir cones were reared and collected to obtain data on the species of insects present. Although no quantitative data were recorded, the collections and mass rearings yielded a greater number and variety of insects than in previous seasons.

¹/ Koerber, T. W. 1960. Douglas-fir cone and seed insect research progress report 1957-1958. U. S. Forest Serv., Pacific Southwest Forest and Range Expt. Sta., 29 pp., illus. (processed).

²/ Koerber, T. W. 1960. Insects destructive to the Douglas-fir seed crop in California. U. S. Forest Serv., Pacific Southwest Forest and Range Expt. Sta., Tech. Paper 45. 36 pp., illus.

This material was sent to taxonomists for identification. On the basis of incomplete reports from these specialists, at least 14 species were obtained which have not been previously reported in association with Douglas-fir cones. Table 1 lists the insects obtained.

Table 1.--Insects reared and collected from Douglas-fir cones of the 1958 cone crop

A. Known or suspected to damage cones and seeds

Lepidoptera

Barbara colfaxiana (Kearf.)
Dioryctria abietella (D. & S.)
Holcocera augusti Heinrich

Coleoptera

*Ernobius socialis Fall

Hymenoptera

Megastigmus spermotrophus Wachtl
Eurytoma sp.

Diptera

Contarinia sp.

Hemiptera

*Leptoglossus occidentalis Heid.
*Gastrodes pacificus (Provancher)

B. Known or suspected predators and parasites

Coleoptera

Enoclerus humeralis (Schffr.)

Hymenoptera

Braconidae

*Bracon n. sp.
*Neoblaucus rufipes Ashm.
*Eubadizon definitum Mues.
*Rogas autographae Vier.
Apanteles petrovae Walley

Ichneumonidae

Exeristes comstockii (Cress.)
Itoplectis evetriae Vier.
Exochus evetriae Roh.

Torymidae

Torymus sp.

Eulophidae

*Tetrasticus coerulescens Ashm.
Tetrasticus sp.
Elachertus proteoteratis (How.)
*Horismenus sp.

Perilampidae

*Perilampus fulvicornis Ashm.

Eupelmidae

Eupelmus brevicauda (Cwf.)

Pteromalidae

Zacalochlora milleri Cwf.
*Homoporus sp.

Trichogrammatidae

*Ufens sp.
*Trichogramma minutum Riley

Bethylidae

*Goniozus longinervis Fouts

*Denoted species previously unreported on Douglas-fir.

REARING OF MEGASTIGMUS SPERMOTROPHUS FROM INFESTED SEEDS

A sample of 110 Douglas-fir seeds from the 1958 crop held in the Orleans insectary yielded 35 adults of Megastigmus spermotrophus. Upon dissection in July the seeds were found to contain 13 additional live Megastigmus larvae. This would indicate that in this instance 27 percent of the population delayed emergence for at least 1 year.

SEQUENCE OF EMERGENCE

About 2 gallons of infested Douglas-fir cones of the 1958 crop were collected near Orleans on April 1, 1959. Cones which had remained on the tree and cones which had fallen to the ground were included in the samples. The cones were held in rearing containers at the Berkeley laboratory where a record was made of the emergence of most abundant species (table 2). Under field conditions, the sequence of emergence would presumably remain the same but would extend over a longer period than in the laboratory. The sequence of attack on the cones would also be the same.

REARINGS FROM INDIVIDUAL CONES

Fifty insect-infested cones were collected from each of four Douglas-fir trees in September of 1959. Each cone was placed in a half-pint cardboard container and held in the Orleans insectary until August 1960 when the cones were examined. At this time a record was made of the number and kind of insects which had emerged from each cone. An additional sample of 40 cones was collected on April 4, 1960, from one of the same trees which supplied the other samples. These cones were treated in the same manner as the others. A summary of the results is given in table 3.

All of the cones used in this study were infested by cone and seed insects. Nearly all of the cones showed damage by Barbara colfaxiana. Megastigmus spermotrophus and Contarinia sp. were prevalent in all of the samples. Dioryctria abietella was present in only a few of the cones.

Insects emerged from 135 of 240 cones. Exactly half of the cones collected in April produced no insects, indicating that under normal field conditions many infested cones may fail to produce adult insects. Hot, dry weather extending into the late fall of 1959 may have been to some extent responsible for the poor emergence. Eighteen specimens of Barbara colfaxiana emerged from the cones along with 54 specimens of insects known to be parasites or predators of Barbara. It was particularly interesting to note that only one of the 24 cones producing specimens of Enoclerus humeralis also produced a specimen of Barbara colfaxiana. This is evidence of the effectiveness of Enoclerus as a predator of Barbara pupae.

A total of 135 specimens of Megastigmus spermotrophus emerged from the cones. The 40 cones collected in the spring produced about the same number of specimens of Megastigmus as the 50 cones collected from the same tree in the fall. Presumably this is due to a high proportion of the seed being trapped in the heavily damaged cones.

No specimens of Contarinia sp. were obtained because this species must leave the cones to pupate in the duff. Probably Enoclerus also leaves the cones to pupate since no specimens were reared from the cones collected in the spring.

Table 2.--Sequence of emergence of insects from Douglas-fir cones in the laboratory, 1959

Insect	April				
	1	5	10	15	20
<u><i>Barbara colfaxiana</i></u>					
<u><i>Megastigmus spermotrophus</i></u>					
<u><i>Bracon</i> sp.</u>					
<u><i>Zachlochlora milleri</i></u>					
<u>Ichneumonids</u>					
<u><i>Eurytoma</i> sp.</u>					
<u><i>Enoclerus humeralis</i></u>					
<u><i>Dioryctria abietella</i></u>					
<u><i>Eupelmus brevicauda</i></u>					

Table 3.--Species and numbers of insects reared from individualDouglas-fir cones, of the 1959 crop

	: No. :							: <u>Eupelmus</u> :	
Sample:	cones:	<u>Barbara</u>	<u>Megastigmus</u>	<u>Exochus</u>	<u>Exeristes</u>	<u>brevi-</u>	<u>Enoclerus</u>		
	<u>colfaxiana</u>	<u>spermotrophus</u>	<u>evetriae</u>	<u>comstockii</u>	<u>cauda</u>	<u>humeralis</u>			
1	50	7	35	6	7	0		13	
2	50	2	17	0	5	44		5	
3	50	6	67	1	1	0		1	
<u>1/4</u>	50	2	8	1	2	0		7	
<u>1/5</u>	40	1	8	3	2	27		0	

1/ Samples 4 and 5 are from the same tree. Sample 4 was collected in September and sample 5 the following April.

STUDIES ON *LEPTOGLOSSUS OCCIDENTALIS* HEID.

In August of 1959, adults and last-instar nymphs of *Leptoglossus occidentalis* were observed feeding on ripening Douglas-fir cones. This was of immediate interest because other members of the genus *Leptoglossus* are well known agricultural pests, and the true bugs in general are notorious pests of seed crops.

A laboratory culture of *Leptoglossus* was established in September to permit observations on the habits and life cycle of the bug.

DESCRIPTION

The first-instar nymph is about 3 mm. long. The antennae are slightly longer than the body and the proboscis slightly shorter than the body. The head and thorax are brown. The abdomen is predominantly orange except for small brown patches surrounding the dorsal abdominal glands and the last three segments. The antennae are brown. The eyes are reddish brown. The legs are brown except for a light yellowish band around the femur. All parts of the insect are liberally covered with tubercles and branching spines.

In the second instar the color pattern remains the same, except for a light yellow band appearing on the tibia. The antenna, legs, and proboscis become greatly elongated; both the antenna and proboscis are considerably longer than the body of the insect.

Rudimentary wing pads appear in the third instar. The color pattern of the body remains unchanged. The light band on the tibia becomes more prominent, and the hind tibia is slightly flattened. The insects are about 7-8 mm. long by the end of the third instar.

The fourth-instar nymph takes on a more reddish appearance than the previous instars. The head and thorax are reddish brown and the abdomen reddish orange. The wing pads are more prominent, overlapping the first segment of the abdomen, and there is a ridge along the margins of the prothorax. The legs are lighter in color than in previous instar. The hind tibia is flattened and expanded as is typical of the coreids. A narrow yellow stripe appears across the expanded portion of the hind tibia. Mature fourth-instar nymphs are 10 to 12 mm. long.

In the fifth instar the head is darker brown. Dark brown spots appear on the thorax, and the wing pads, which now extend to the second or third abdominal segment, are dark brown toward the distal end. Varying amounts of dark brown appear on the abdomen. Some individuals are almost solid brown in the fifth instar. A ridge bearing six prominent spines appears on posterior edge of the hind femur.

The adults vary from reddish brown to dark gray brown in color. The dorsal side of the abdomen, which is normally covered by the wings, is

marked with yellow or light orange. Heideman^{3/} provides a complete description of the adult.

REPRODUCTION

Both males and females mate repeatedly, perhaps several times a day. Gravid females with an unlimited food supply produce an average of 12 eggs per day. When undisturbed, an ovipositing female normally deposited an entire day's batch of eggs at one time and place.

In the laboratory, eggs were usually deposited in one or two rows on the side of the rearing box; rarely were they deposited on the floor. In the field eggs are deposited in a single row on a needle of the host tree. In the laboratory the eggs hatched in about 10 days.

FEEDING HABITS

L. occidentalis has a long proboscis consisting of the usual four stylets ensheathed in a modified labium. When feeding on seeds in the laboratory, the insects select a suitable seed, evidently employing sense organs on the tip of the labium and on the front tarsi. When a seed has been selected the insect assumes a position with the anterior end of the body raised. The front tarsi are placed close together on the seed. The proboscis is extended downward in front of the insect contacting the seed between the front tarsi. The antennae are lowered so the tips are held near the point of attack on the seed. Under a microscope a droplet of fluid may be seen rapidly appearing and disappearing at the tip of the proboscis. The insect has very large salivary glands which probably serve as a source of secretions to dissolve or soften the seed coat so the stylets are sent deep into the seed. The labium is bent at the basal joint and the two basal segments fold back against the ventral side of the thorax. Sometimes the labium is completely withdrawn and held in its normal resting position while the unsheathed stylets remain in the seed. Under these circumstances the bugs have been observed to thrust the thin stylets into a seed almost to their full length.

When feeding on seeds within the cones in the field, the behavior of the insect was much the same as observed in the laboratory. The stylets penetrate the cone at a carefully selected point between the front tarsi which the insect places close together on the surface of the cone. The stylets are driven through the cone scales to reach the seeds, an operation usually requiring the entire length of the stylets. The labium is held in the resting position against the ventral side of the insect.

After the seed is penetrated, feeding may continue for several hours. A large part of the solid portion of the endosperm is removed in the course of repeated feedings. The material removed is probably dissolved by the saliva of the insect and then imbibed. When feeding is completed,

^{3/} Heideman, O. 1910. New species of Leptoglossus from North America. Ent. Soc. Wash., D. C. Proc. 12(4): 191-197.

the insect quickly withdraws its stylets and returns them to their labial sheath. The puncture in the seed coat is marked by a minute conical fleck of white material, possibly dried saliva.

A series of experiments was conducted to determine what species of conifer seeds were accepted as food by L. occidentalis. Twelve first-instar nymphs were confined in a half-pint liquid food carton with enough seeds to cover the bottom of the carton. Water was supplied on a cotton wick in a shell vial inserted through a hole in the bottom of the carton. The top of the carton was covered with clear plastic film to permit observation. Two tests were run on each of 13 species of seed:

Douglas-fir	<u>Pseudotsuga menziesii</u> (Mirb.) Franco
Bigcone-spruce	<u>Pseudotsuga macrocarpa</u> (Vasey.) Mayr
Ponderosa pine	<u>Pinus ponderosa</u> Laws.
Jeffrey pine	<u>Pinus jeffreyi</u> Grev. and Balf.
Coulter pine	<u>Pinus coulteri</u> D. Don
Digger pine	<u>Pinus sabiniana</u> Dougl.
Sugar pine	<u>Pinus lambertiana</u> Dougl.
Monterey pine	<u>Pinus radiata</u> D. Don
Red fir	<u>Abies magnifica</u> A. Murr.
White fir	<u>Abies concolor</u> (Gord. and Glend.) Lindl.
Mountain hemlock	<u>Tsuga mertensiana</u> (Bong.) Carr.
Port-Orford-cedar	<u>Chamaecyparis lawsoniana</u> (A. Murr.) Parl.
Incense-cedar	<u>Libocedrus decurrens</u> Torr.

One test used broken seeds and the other used unbroken seeds. The insects were able to grow from the first instar to maturity on all types of seed tested except Port-Orford-cedar, which may be nutritionally inadequate. The nymphs easily penetrated the Port-Orford-cedar seeds, but all nymphs confined with these seeds died in the second instar. Tests showed that the bugs were able to reach the second instar without feeding. The first-instar nymphs were unable to penetrate the thick shell of Digger pine seeds, but were able to grow to maturity on broken seeds. Further tests revealed that the later instars were able to penetrate the seed coat of Digger pine and reach maturity on this diet.

EFFECT OF FEEDING ON SEEDS

It was found that the endosperm of seeds fed upon by L. occidentalis was greatly shrunken and exhibited a characteristic spongy degeneration. In the seeds which were most heavily damaged, the endosperm was almost entirely destroyed, the remaining tissues being reduced to a shriveled yellow wafer-like remnant. This distinguishes them from seeds which are hollow due to pollination failure in which the inner integument of the seed coat is present as a shriveled, chalk white, cylindrical structure.

Leptoglossus feeding was clearly established as the cause of the shrunken endosperm by exposing approximately 1,000 Douglas-fir seeds to feeding by 12 first-instar nymphs. Equal numbers of seeds from the same seed

lot served as untreated checks. The test was replicated four times. The insects fed upon the seeds and grew to adults in 35 to 40 days. After 40 days, 25 exposed and 25 unexposed seeds from each replicate were examined, and a large proportion were found to have shrunken endosperms. Unexposed seeds from the same tree had normal endosperms. The results of the experiment are presented in table 4.

Table 4.--The effect of feeding by *Leptoglossus occidentalis* Heid. on Douglas-fir seed

Replicate	Exposed to feeding			Not exposed to feeding		
	Shrunken	Hollow	Normal	Shrunken	Hollow	Normal
1	12	9	4	0	14	11
2	10	15	0	0	9	16
3	18	2	5	0	8	17
4	17	5	3	0	4	21
Total	57	31	12	0	35	65

In another test 12 first-instar nymphs were confined to small Douglas-fir trees. The insects attempted to feed upon the needles, buds, and twigs, but in the six replicates of the test all the insects died in the second instar. Later-instar nymphs and adult bugs also failed to survive on Douglas-fir foliage.

Both the nymphs and adults tend to be gregarious. When resting, most of the individuals in a rearing container tended to gather in a cluster on the side of the box. A similar, though less marked, tendency was noted in the field.

STUDIES OF THE SEASONAL HISTORIES OF CONE AND SEED INSECTS

In the course of previous work, it was determined that Douglas-fir cone and seed insects make their attack on the cones in early spring. A series of observations was initiated in 1959 to determine more exactly the time of attack on the cones and also to study the early life of the immature insects. The observations were made at three locations near Orleans. The three locations chosen were readily accessible, had small open-growing trees which could be easily climbed, and on the basis of bud counts showed promise of good cone crops.

EXPERIMENTAL AREAS AND CONDITIONS

The Coopers Ranch location is a southwest-facing slope at an elevation of 2,000 feet, about 9 miles southwest of Orleans. Open-grown Douglas-fir trees from 30 to 70 feet tall are scattered over a grassy meadow. The meadow is flanked by a closed stand composed mainly of 60- to 100-foot Douglas-firs and small numbers of ponderosa pine and incense-cedar. This area had been under observation since 1957, and the particular tree chosen for this study has had better than average cone crops in every year since 1956.

The Black Mountain location is a small flat about 6 miles south of Orleans, at an elevation of 2,500 feet near the top of a gentle south-east-facing slope. The central part of the flat is a wet meadow. Around the fringe of the flat are Douglas-fir trees from 60 to 120 feet tall, some of which are fairly open grown. The surrounding stand is composed of virgin Douglas-fir with a small amount of incense-cedar and hardwoods. The trees of this location had not produced a good cone crop since 1956. Two trees about 100 feet tall growing on the north side of the meadow were used in this study.

The third location, Bloody Camp, is a ridge-top meadow about 14 miles southwest of Orleans at an elevation of about 3,000 feet. The ridge top overlooks the junction of the Klamath and Trinity Rivers and is more subject to cool, cloudy, or foggy weather than the other locations. Open-grown Douglas-fir trees 60-100 feet tall are scattered over the meadow. Two of these, on a small knoll near the center of the meadow, were used in this study. The surrounding timber is a nearly pure stand of large Douglas-firs with an understory of hardwoods. The trees of this area had a good cone crop in 1958 but were not studied previously.

The weather in the study areas was somewhat warmer and drier than normal during the spring of 1959. U. S. Weather Bureau data showing the departure from the long-term means for the North Coast area are given in table 5. What effect, if any, variations of the magnitude observed have on these insects is not certain. A probable effect is that given events in the life cycle occurred somewhat earlier than normal.

Table 5.--Departures of 1959 temperature and rainfall from long-term means for the North Coast area of California

Month	: Departure from	: Departure from	: Average temperature
	mean temp.	mean rainfall	at Orleans*
	Degrees F.	Inches	Degrees F.
March	+ 3.2	- 2.26	51.1
April	+ 3.5	- 2.39	57.9
May	+ 0.3	- 1.21	58.6
June	+ 2.9	- .74	66.7

*Long-term means are not available for Orleans.

Temperature data as recorded at the U. S. Weather Bureau installation at Orleans are presented in figure 1.

Observations were started on March 20. At this time the snow line in the mountains was between 3,500- and 4,000-foot elevation. The Douglas-fir cone buds had not yet opened, and there was no sign of insect activity at any of the locations under study. At Orleans (elevation 400 feet), the Douglas-fir cone buds had started to open and adults of Barbara colfaxiana were emerging from infested cones in the insectary.

Cone samples were collected at intervals until August 25. The cones were dissected and a record of the species and numbers of insects and the damage they caused was kept.

BARBARA COLFAXIANA

Oviposition of Barbara colfaxiana started after April 4 and was well under way by April 24. April 10 would be a good approximation of the actual start of oviposition. The oviposition extended at least through the first week of May. At the coldest location studied, a single, unhatched egg was found on June 5. However, it is not likely that many eggs were deposited here after May 25. If any were deposited, the eggs or their shells should have been found on the cones collected in early June.

Two species of parasites (Trichogramma minutum and Ufens sp.) were found to attack the eggs. In one of the samples taken at Black Mountain the egg parasites caused mortality in excess of 10 percent of the combined egg and larval populations. It also seemed that eggs deposited toward the end of the oviposition period were more likely to be parasitized than the first eggs deposited.

When the eggs hatch the larvae quickly establish themselves in superficial mines in the cone scales. There appears to be some mortality at this stage since hatched eggs were found in the absence of larvae. There is commonly a flow of pitch at the point of attack on the cones but this appears to be neither helpful nor detrimental to the larva.

The extension of the larval mine progresses quite slowly after it is first established, and several weeks elapse before the larvae actually begin to destroy seeds. At Coopers Ranch where the attack was well under way on April 24, the larvae did not reach the seeds until the end of May or beginning of June. On June 4, the average number of seeds destroyed at Coopers Ranch was only 1.3 seeds per larva. At Grasshopper Prairie, which is a cooler site than the others, the larvae had not yet reached the seeds by June 5.

The position of the larvae near the surface of the cone for an extended period would tend to expose them to attack by parasites and predators for a longer period than had been expected. In point of fact, at least three of the parasites which have been reared from Barbara larvae

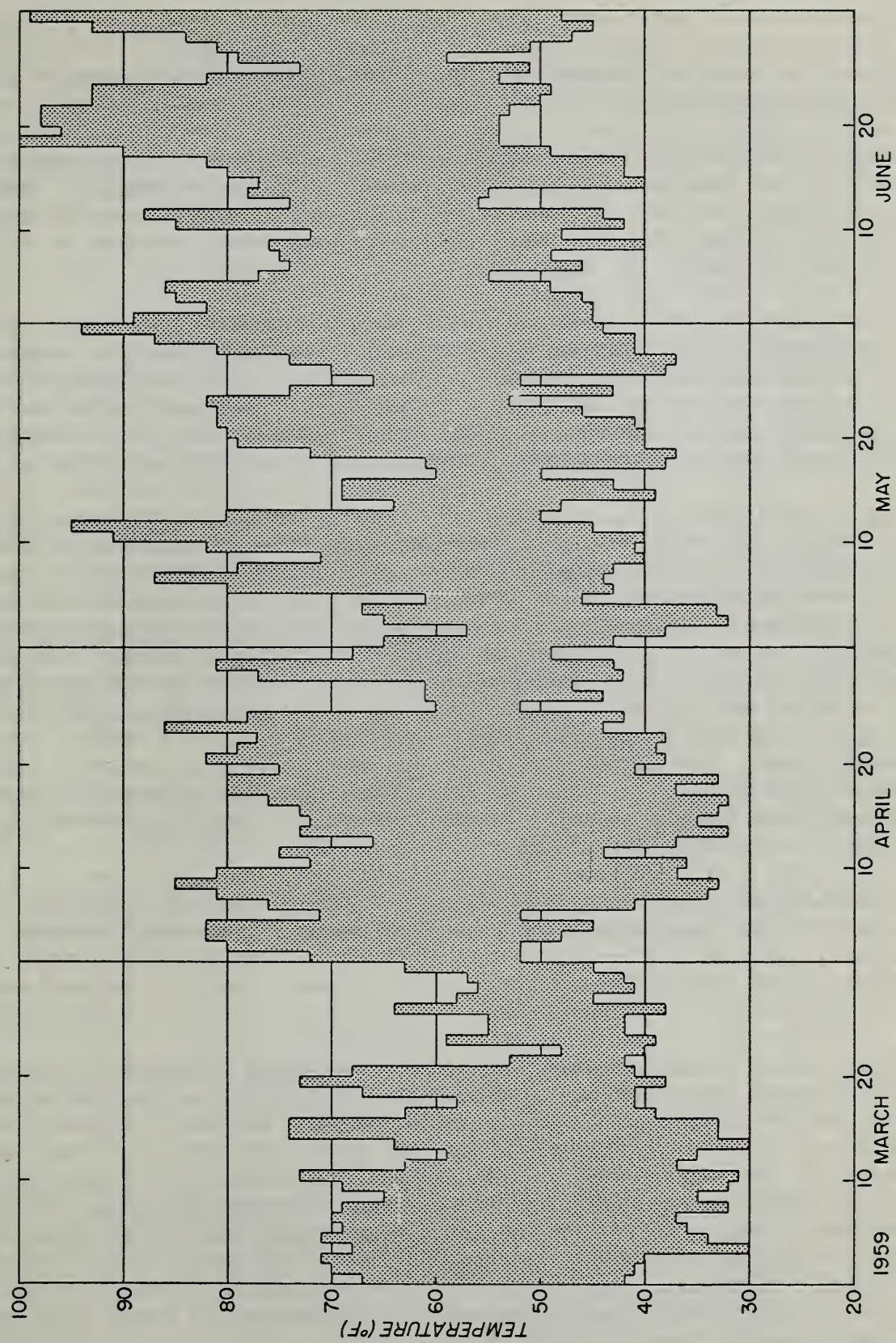


Figure 1.--Temperatures from March 1 to June 30, 1959, as recorded by the
U. S. Weather Bureau at Orleans, California.

probably attack their host at this time. They are Apanteles petrovae, a braconid with a short ovipositor; Gonozius longinervis, a chalcid without an exserted ovipositor; and an undetermined larvavorid fly with no specialized ovipositor.

Further evidence of the vulnerability of the larvae at this time is given by the data on the number of larvae in the cone samples. Some rather large population reductions may be noted between the May and June collections from the same trees. Perhaps some predator is able to reach the larvae at this time.

If the larvae do not reach the seed-bearing region of the cone until 4 to 6 weeks after the initial attack, the possibilities for chemical control are considerably enhanced. The larvae lying near the surface may be susceptible to slow-acting systemics or to insecticides having a fumigant action. Either of these methods would have an advantage in that the timing of the treatments would not be especially critical.

Samples collected July 21 showed the feeding damage by Barbara colfaxiana virtually complete. At the lower elevation site, Coopers Ranch, pupation was complete. At Grasshopper Prairie, elevation 3,000 feet, the larvae were nearing maturity. More larval mortality, which in part was due to the maturity and emergence of Apanteles petrovae, had occurred. Apanteles is a solitary internal parasite of Barbara larvae. It is therefore certain that each Apanteles cocoon represents one Barbara larva which was killed by Apanteles. On the basis of the numbers of Barbara pupae and Apanteles cocoons present in the July sample from Coopers Ranch, the mortality due to Apanteles was 24.2 percent. The sample from one of the trees at Grasshopper Prairie showed 36.8 percent mortality due to Apanteles. Smaller numbers of Apanteles cocoons were found in cone samples from other trees.

By late August, pupation by Barbara was complete at all locations. Total mortality from egg to pupa, while quite variable from one location to another, reached impressive levels in some instances. For example, the Coopers Ranch population suffered a 66 percent reduction between May 7 and July 21.

The amount of damage caused by Barbara colfaxiana averaged slightly over 21 seeds per cone, well within the range expected from infestations of a similar level studied in previous years. The fact that most of the damage does not occur until June or early July may be of some importance both for the formulation of control practices and for the development of sampling methods. Due to high mortality of the young larvae, the damage fell well below that which might have been expected on the basis of egg counts. The cones were able to heal over nearly all of the early mines which were vacated by the mortality of small larvae. By the time the surviving larvae matured there was no longer any evidence of their less fortunate siblings.

DIORYCTRIA ABIETELLA

The larvae and eggs of Dioryctria abietella were conspicuously absent from the cone samples taken in early summer. A single Dioryctria larva was found in the first cone sample taken in April at Coopers Ranch. Dioryctria was not found again until the latter part of July. It appears that the heaviest attack by Dioryctria occurred in the first or second week of July.

The single larva found in April may represent an earlier spring generation. If this is so, we can postulate that a small first or spring generation produced adults about July 1. These insects produced eggs which developed into a much larger second generation which damaged the cones during July and early August. The larvae which matured in August either transformed to adults and deposited overwintering eggs or delayed transformation until the following spring. Adults of Dioryctria are, in fact, found both in fall and in spring, so it appears that both alternatives may be true.

The damage estimates obtained for Dioryctria averaged 5.5 seeds per cone. These estimates are none too good because most of the Dioryctria larvae did not invade the cones until after extensive damage from Barbara colfaxiana had occurred. Consequently, there were few seeds left to eat and damage done by Dioryctria would tend to be obscured by and might be confused with Barbara damage.

MEGASTIGMUS SPERMOTROPHUS

Oviposition by Megastigmus spermotrophus was observed on May 9. The eggs and small larvae were not detected in the seeds at that time because they were not examined under suitable magnification. By July 21, the larvae could easily be found without magnification. This insect was found in 15 percent of the seeds at Coopers Ranch, in up to 43 percent of the seeds at Black Mountain, and was altogether absent at Grasshopper Prairie.

Megastigmus evidently suffered heavy mortality due to the feeding activities of Barbara colfaxiana. At Coopers Ranch, larvae of M. spermotrophus were found in seeds of 18 out of 25 cones. They destroyed an average of 4.3 seeds per infested cone. The maximum number of seeds destroyed in a single cone was 12. However, these data are to some extent misleading since some seeds which were originally infested by Megastigmus were subsequently destroyed by Barbara larvae. In the absence of the Barbara larvae the average Megastigmus population would probably be near 10 per cone. Figure 2 shows graphically the inverse correlation between the number of seeds destroyed by Barbara and the number of seeds in the same cone destroyed by Megastigmus. At Black Mountain where high populations of both Barbara and Megastigmus were found in the same cones, probably half to two-thirds of the Megastigmus population was destroyed. While the quantity of seed destroyed by Megastigmus was small, it is easy to imagine what might happen if

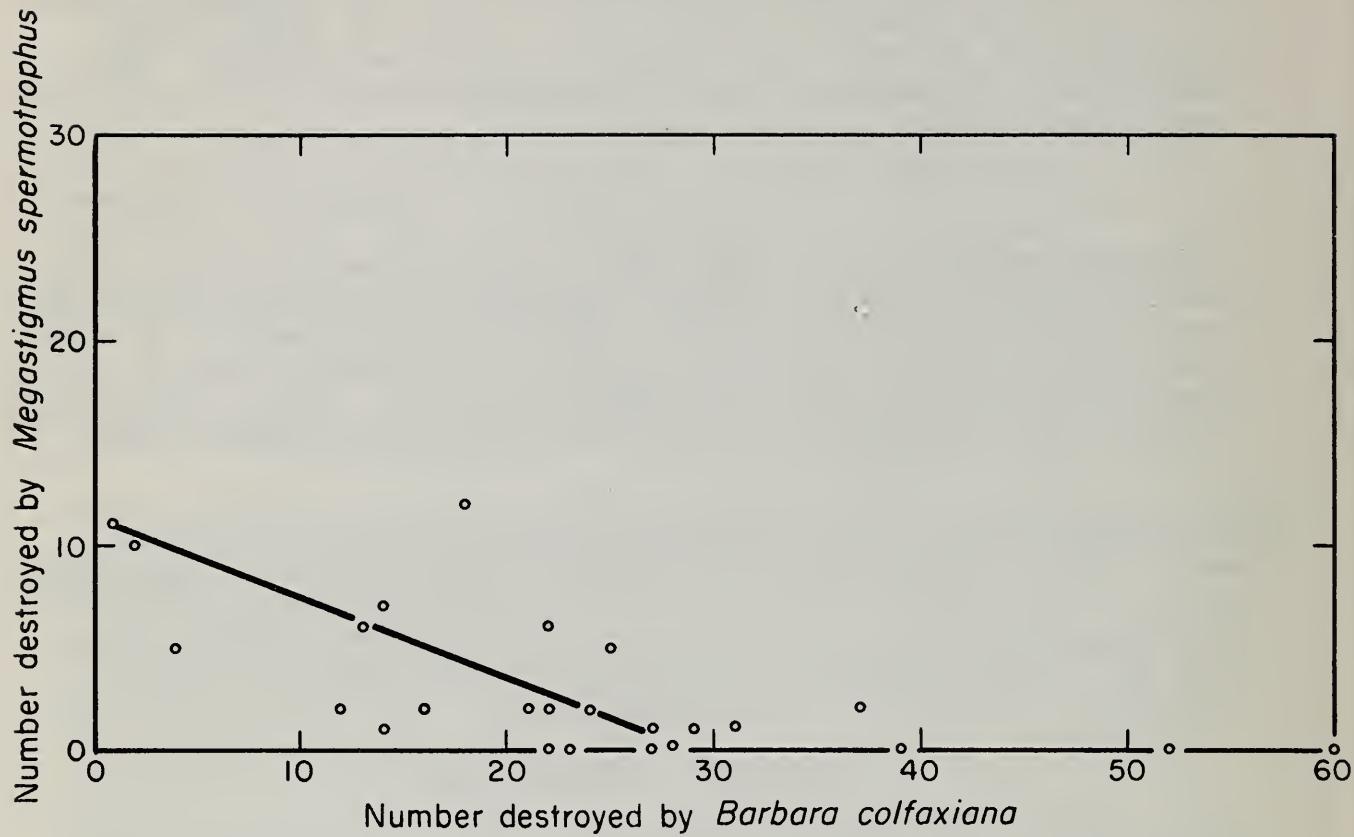


Figure 2.--Relationship between number of seeds destroyed per cone by *Barbara colfaxiana* and *Megastigmus spermotrophus*.

Megastigmus were freed from competition by Barbara. In view of the fact that no parasites or predators have yet been found to attack Megastigmus in northern California, it seems that competition by Barbara colfaxiana may be the most important single factor controlling the population level of Megastigmus spermotrophus.

CONTARINIA SP.

Contarinia sp. is known to deposit eggs between the scales of Douglas-fir cones as soon as the cone buds open in the spring. The cones sampled were not attacked by Contarinia or the eggs had hatched before the cones were collected, since none were found. Evidently the eggs hatch quite soon after oviposition, and the remains of the eggs and the new larvae in the cone tissue cannot be detected without microscopic examination.

The galls formed by the Contarinia larvae were easily seen in cones collected at Black Mountain on June 6. At this time Contarinia had destroyed 20 to 25 percent of the seeds in the Black Mountain cone samples. When the next samples were collected on August 25, damage by Barbara colfaxiana was so extensive as to preclude any realistic estimate of Contarinia damage. Very little Contarinia damage was found in the cone samples from Grasshopper Prairie and none was found in the samples from Coopers Ranch. Here again it is evident that feeding by Barbara colfaxiana is detrimental to the larvae of Contarinia. At least one parasite is known to attack Contarinia in large numbers, so that the role of Barbara in controlling Contarinia is probably not so important as is the case with Megastigmus.

CONE-BAGGING EXPERIMENTS

MATERIALS AND METHODS

Cone-bearing branches on a total of seven Douglas-fir trees at Coopers Ranch, Black Mountain, and Bloody Camp were covered with bags of 32-mesh lumite screening by April 2, shortly before the cone buds opened. Cone buds began opening on April 10. Somewhat more than half of the cones which developed inside the screen bags were exposed to insect attack by removing the bags for a predetermined period. The bags were replaced at the end of the exposure period and the cones allowed to mature.

The mature cones were harvested in late August and early September. A sample of cones which were never covered, that is unprotected from insect attack, was collected from each tree along with the bagged cones. The cone samples were placed in bags of 32-mesh lumite which were hung in the insectary at Orleans until the cones were dry. Any insects which emerged during the drying period and seeds which fell from the cones were retained in the bags.

Each cone was completely dissected by removing the scales one at a time from the cone axis, starting at the base and proceeding toward the tip of the cone. A record was made of the length of the cone as measured from the bud scales on the petiole to the distal end of the bracts. The number and kind of insects found in each cone were recorded, along with the number of seeds destroyed by each species of insect.

The seeds which were found in the cones were retained to form a series of seed lots each of which consisted of all the seeds from all the cones in each cone sample. The seeds were dewinged by rubbing them between soft paper towels and sifted by hand using a sieve having openings 2 millimeters in diameter. Large pieces of debris, such as broken seeds and cone parts, were removed by hand-picking. The samples of clean seed were weighed to the nearest 0.01 gram on a torsion balance. The number of seeds in each sample was determined by actual count in the case of the smaller samples. The number of seeds in the larger samples was estimated by counting the number of seeds in four 1-gram subsamples and using the mean number of seeds per gram and the weight of the sample to calculate the total number in the sample.

Four subsamples of 50 seeds each were drawn from each seed lot. These seeds were broken in half to determine the condition of the endosperm. If fewer than 200 seeds were obtained from a cone sample, all of the seeds were broken. The seeds were classified into four groups: sound, hollow, infested by Megastigmus, or damaged by Leptoglossus. Sound seed contained an apparently normal endosperm, though no germination tests were made. Hollow seeds were those having normal, fully formed seed coats but containing only a wisp of dried white tissue, the inner integument. According to Roy^{4/} the seed coat and inner integument develop without fertilization so that the hollow seeds encountered result from failures in pollination or fertilization. The data obtained by the foregoing procedure form the basis for the following series of tables which show the results of the cone-bagging experiment.

RESULTS

Insect Infestations

Detailed data on the location of the trees used in the experiment, the dates on which cones were exposed and recovered, and the number of cones in each sample, are presented on table 6. This table shows the gross effect of cone bagging upon the extent of insect infestation. The cones which were never covered may be considered to show the normal infestation on each particular tree. The infestations in the cone samples which were bagged, then exposed for a predetermined period, are considered to reflect the insect attack during the period when the cones were

^{4/} Roy, D. F. 1960. Douglas-fir seed production and dispersal in Northwestern California. Pac. Southwest Forest and Range Expt. Sta. Tech. Paper 49. 22 pp., illus.

Table 6.--Insect infestation of Douglas-fir cones in cone-bagging experiment, 1959

Locality	: Tree :		:Number cones in sample	Percent infested by		
	:number:	Exposure period:		:Barbara:	:Dioryctria:	:Contarinia:
Coopers Ranch	1	Never exposed	51	3.9	9.8	0.0
Coopers Ranch	1	Apr. 24 to May 7	45	40.0	53.5	.0
Coopers Ranch	1	May 7 to June 4	35	40.0	80.0	.0
Coopers Ranch	1	Never covered	60	83.5	71.7	20.0
Coopers Ranch	2	Never exposed	11	9.1	54.5	.0
Coopers Ranch	2	May 7 to June 4	26	.0	69.5	.0
Coopers Ranch	2	Never covered	44	47.8	52.4	43.2
Black Mountain	1	Never exposed	16	25.0	18.7	.0
Black Mountain	1	May 9 to June 6	32	78.2	50.0	.0
Black Mountain	1	Never covered	25	100.0	28.0	72.0
Black Mountain	2	May 9 to June 6	37	83.9	3.5	.0
Black Mountain	2	Never covered	13	100.0	30.8	30.8
Black Mountain	3	Never exposed	37	70.0	38.0	.0
Black Mountain	3	Never covered	33	97.0	.0	63.6
Bloody Camp	1	Never exposed	20	.0	25.0	.0
Bloody Camp	1	May 8 to June 4	10	.0	.0	.0
Bloody Camp	1	Never covered	25	24.0	60.0	28.0
Bloody Camp	2	Never exposed	54	.0	20.0	.0
Bloody Camp	2	May 8 to June 4	33	3.1	21.2	.0
Bloody Camp	2	Never covered	60	28.3	21.6	15.0

exposed. The cones which were never exposed are also infested to some extent, indicating that some insects were able to gain entry to the closed cone bags.

A small percentage of the cones which were never exposed were infested by Barbara colfaxiana. A considerably larger percent of the cones which were covered and then exposed for a short time were infested. A large percent of the cones which were never covered were attacked by Barbara.

The obvious conclusion is that considerable oviposition of Barbara colfaxiana took place during the period when the cones were exposed. However, the oviposition period did not entirely coincide with the exposure period so that the unprotected cones were more heavily attacked than those exposed for a short period. The infestation of unexposed cones indicates the insects can and did enter the bags used to protect the cones and were inclined to do so under conditions of high population pressure.

Infestation by Dioryctria abietella did not differ consistently between cone samples receiving different bagging treatments. Evidently the larvae of Dioryctria were able to easily enter the cone bags.

Unprotected cones were infested by Contarinia sp. to the extent of 15 to 72 percent. None of the cones receiving any of the bagging treatments were infested. This clearly indicates that oviposition by Contarinia did not take place during the exposure period and that the insects were not able to enter the bags.

Seed Yield and Quality

The best measure of the damage caused by the insects involved in this study is the reduction in the quantity and quality of seed produced (table 7). The quantity of seed has been presented both as milligrams per cone and number per cone. Douglas-fir seed is normally bought and sold by the pound, but natural seedfall and the stocking of seedlings is usually expressed in numbers per acre. The quantity of seed destroyed by insects is expressed in number per cone in the remainder of this report.

A bit of incidental information obtained in compiling these figures concerns the variation in the weight of Douglas-fir seeds. The number of seeds in the 1-gram samples ranged from 65 to 117, but the variation in number of seeds in the samples from any one tree was less than 10 percent. The seeds from Coopers Ranch tree A averaged 74 to the gram, while the seeds from one of the samples from Bloody Camp tree B averaged 109 per gram.

The figures on seed yield (table 7) show clearly the reduction caused by insect damage to the unprotected cones. The reduction in the quantity of seed produced is mainly due to the feeding activities of Barbara colfaxiana and Dioryctria abietella. The reduction in the quality of

Table 7.—Seed yield from Douglas-fir cones in cone bagging experiment, 1959

Locality	Tree : number	Exposure period	size :	Sample:	Seed yield	Sound	Hollow	Megastigmus	Leptoglossus
				Cones	Mg. Number	Pct.	Pct.	seed : infested	damaged
Coopers Ranch	1	Never exposed	51	678	48.8*	71.5	26.0	0.0	2.5
	1	Apr. 24 to May 7	45	428	29.7*	74.5	24.0	.0	1.5
	1	May 7 to June 4	35	144	11.3	56.6	29.7	12.2	1.5
	1	Never covered	60	47	5.8	10.5	33.0	15.5	41.0
Coopers Ranch	2	Never exposed	11	330	30.0	55.0	39.5	.0	10.5
	2	May 7 to June 4	26	166	20.7	32.5	34.5	17.0	15.0
	2	Never covered	44	82	14.3	5.5	38.0	23.0	33.5
Black Mountain	1	Never exposed	16.	476	34.5*	62.5	37.0	.5	.0
	1	May 9 to June 6	31	103	10.0	32.0	25.0	43.0	.0
	1	Never covered	25	10	.8	73.7	15.8	10.5	.0
Black Mountain	2	May 9 to June 6	37	21	2.6	17.9	63.2	18.9	.0
	2	Never covered	13	3	.6	.0	37.5	62.5	.0
Black Mountain	2	May 9 to June 6	37	415	35.7*	61.5	38.0	.0	.5
	2	Never covered	13	37	5.7	19.3	32.6	43.3	4.8
Black Mountain	3	Never exposed	38	568	37.6	69.0	31.0	.0	.0
	3	Never covered	33	407	35.7	59.0	38.5	.0	2.5
				329	27.3	60.5	17.5	.0	22.0
Bloody Camp	1	Never exposed	20	483	42.4*	80.5	19.0	.0	.5
	1	May 8 to June 4	9	342	39.0*	47.5	52.5	.0	.0
	1	Never covered	25	268	30.3*	68.0	15.0	.5	16.5

* Calculated yield based on mean number of seeds in 4 one gram samples.

the seed, expressed as the percentage of sound seed in the samples, is due to the feeding of Megastigmus spermotrophus and Leptoglossus occidentalis.

Each Megastigmus larva completes its life cycle within a single seed. The insect completely destroys the endosperm and embryo of the seed, but the external appearance of the seed is not altered.

Megastigmus-infested seeds were nearly as prevalent in seeds from cones exposed from May 7 to June 4 as in seeds from cones which were never bagged. This would indicate that most of the oviposition by this insect took place during the period when the cones were exposed.

Some of the data on Megastigmus infestation obtained from cone samples collected at Black Mountain are of questionable validity because of the small number of seeds used. However, two of the samples from Black Mountain, which are based on 310 and 188 seeds respectively, had Megastigmus infestations of 43 percent. In contrast, Megastigmus was virtually absent from the seed samples collected at Bloody Camp.

Two of the areas under study were observed to harbor high populations of Leptoglossus occidentalis during the 1959 growing season. Damage which could be attributable to this insect was found in the seeds sampled for this study. Although we cannot be certain that Leptoglossus is the sole cause of all the shrunken endosperms, seeds showing this defect were classified as Leptoglossus damaged. The cone bags evidently offered a high degree of protection from the causative agent of the shrunken endosperm. The incidence of shrunken endosperms in seed samples from unprotected cones ranges from slightly more than two times to over thirty times the amount in seed samples from protected cones on the same tree. The cones which were exposed for only a short time show about the same amount of damage as the corresponding unexposed samples. This would support the hypothesis that an insect which was excluded by the screen bags was the causative agent.

In short, we have observed that a portion of the seed in certain of the samples exhibits a type of damage which could have been caused by an insect which was present on the trees when the samples were obtained. However, we have not eliminated the possibility that part of the damage was caused by another agent.

Douglas-fir cones always contain some seeds which fail to develop normally. Characteristically these seeds consist of a flattened, scale-like vestige of seed coat and a seed wing which is usually smaller than normal. These seeds never contain an endosperm and are generally called "aborted seeds." Most of the aborted seeds are found in the basal portion of the cone, although some may be found in the remainder of the cone. Aborted seeds were not counted in this study and may account for some of the variation in the number of seed per cone.

Infestation by *Barbara colfaxiana*

In this test, Barbara colfaxiana was the most prevalent insect in the cones and was also responsible for more damage than any other species. Table 8 (appendix) presents a detailed accounting of the damage along with supplementary data which aid in interpretation. The data on cone length are included to provide a rough estimate of the stage of cone development at the time of bagging. Considering the cone measurements as an index of cone development, it appears that the cones exposed at Bloody Camp from May 8 to June 4 were in a stage of development comparable to those exposed at Coopers Ranch from April 24 to May 7.

It appears that bagged cones regularly grow larger than unbagged cones on the same tree. The protection from insect attack or an amelioration of physical conditions due to the bag might account for the differences.

The extent to which the cones were infested is expressed as the percent of cones in each sample and also as the average number of pupae per cone. The strong correlation between these two measurements is immediately apparent. Using either figure it is obvious that the cones which were never protected were heavily infested. Those which were exposed for a short period were infested to a lesser extent and those which were never exposed were lightly infested. The data for the different treatments are not strictly comparable because larvae in cones which were not covered were subject to more predation and parasitism than those in bagged cones. Part of the inequality in larval mortality is illustrated by the data on the number of Apanteles petrovae cocoons in each sample.

Apanteles larvae mature shortly before the Barbara larvae spin cocoons. Apanteles emerges from the host larva and consumes every part of it except the head capsule. The mature Apanteles larva pupates in the cone in a white cocoon about the size and shape of a rice grain. These distinctive cocoons remain in the cone as presumptive evidence of the death of a number of Barbara larvae equal to the number of cocoons.

Apanteles cocoons were present in all of the samples of unprotected cones and in one of the cone samples which was exposed from May 9 to June 6. In several samples, notably those from Bloody Camp, mortality due to parasitism was high.

Data obtained by periodic dissection of cone samples showed large reductions in populations of Barbara larvae between successive cone samples taken from the same tree. The data on larval mortality available at the present time indicate that the mortality of Barbara larvae in unprotected cones may be from 50 to 75 percent. The agents responsible for this mortality are for the most part unknown and the extent to which these mortality agents operate inside the screen covering the cones cannot be determined. However, it is probably safe to assume that mortality of Barbara larvae was greater in uncovered cones than in covered cones and that the larval population and intensity of

attack on the cones differed by at least as much or more than the differences indicated by the numbers of pupae in samples from the various treatments.

The data obtained from the cone dissections revealed that most of the damage caused by Barbara larvae occurs during a short period when the larvae are nearing maturity. This is after most of the mortality due to unknown causes has occurred. When the number of seed destroyed per cone is plotted against number of larvae, as indicated by the number of pupae plus the number of Apanteles cocoons per cone, a very consistent relationship is revealed (figure 3). The data also show that the period when cones were exposed coincided with a considerable part, but not all, of the oviposition period of B. colfaxiana. None of the cone samples receiving a short exposure period had Barbara populations as high as the corresponding unprotected cone samples, and most fell well below the population levels in the unprotected samples. This would indicate that part of the oviposition took place before or after the exposure period. The data obtained from the sample exposed from April 24 to May 7 at Coopers Ranch, together with the data obtained from cone dissections, indicate that considerable oviposition by B. colfaxiana did, in fact, take place before the second week of May.

Several samples of cones which were never exposed carried Barbara pupae. The insects probably entered the cone bags as first-instar larvae which are small enough to pass through the netting used for the bags. The adult moths are far too large to enter the bags and oviposition through the netting seems unlikely.

A high percentage of the unexposed cones at Black Mountain were infested by B. colfaxiana. This suggests that the small larvae are inclined to migrate when population levels are high (58 larvae in 12 cones at Black Mountain).

Infestation by *Dioryctria abietella*

Larvae of Dioryctria abietella were prevalent in nearly all the cones examined, frequently causing as much or more damage than B. colfaxiana. A detailed accounting of the damage done by Dioryctria is presented in table 9 (appendix). The supplementary cone data are again included as an aid to interpretation.

Both the larval population in the cones and the amount of damage are quite variable; and furthermore, there is no consistent relationship between the bagging treatments and the damage to the cones. According to the data obtained from cone dissections, Dioryctria larvae attacked the cones in early July, a full month after the end of the exposure periods. At this time all the cones which received the bagging treatment were covered and only those which were never covered were exposed. However, both protected and exposed cones were infested, and in three sets of samples the exposed cones suffered less damage than the supposedly protected cones on the same tree.

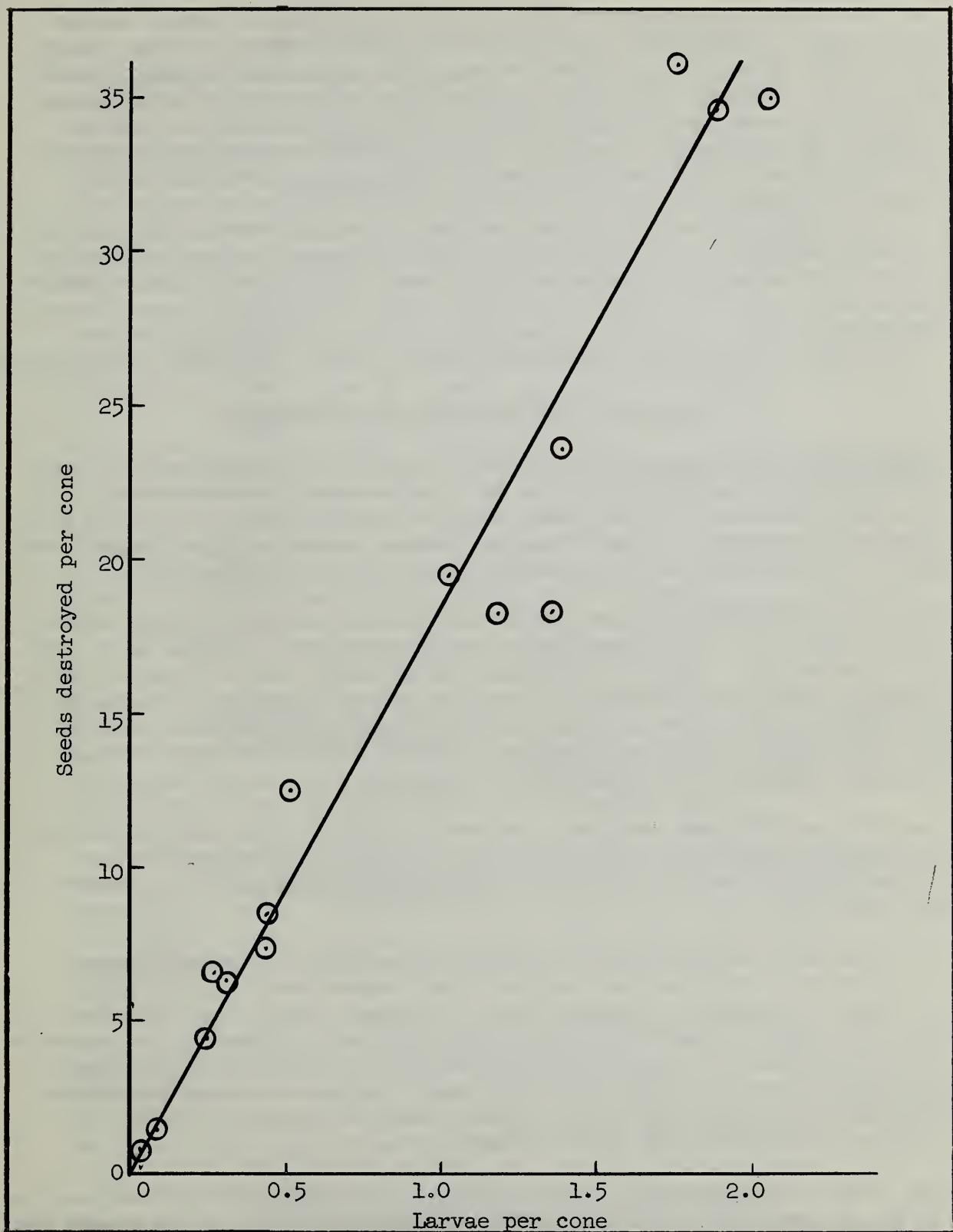


Figure 3.--The relationship between the number of Barbara larvae per cone as determined by the number of Barbara pupae and Apanteles cocoons and the number of seeds destroyed per cone.

All the evidence suggests that the attacks are made by small larvae which seek out the cones and are able to pass through the mesh of the cone bag. Under these circumstances, both bagged and unbagged cones would be attacked. Parasitism, predation, and increased competition from other cone insects would account for lower figures for larval population and damage in exposed cones. Another factor which should be considered is the fact that mature Dioryctria larvae leave the cones to pupate. The mature larvae would be unable to get out of the cone bags but would be free to leave unbagged cones. This seems to have happened at Black Mountain. If the larvae were gone when the cones were examined, the damage they caused should remain as evidence of their presence. Two of the cone samples from Black Mountain show essentially this situation. They had few or no Dioryctria larvae but showed considerable amounts of damage of the type done by Dioryctria.

Infestation by *Megastigmus spermotrophus*

Megastigmus spermotrophus populations destroyed an important part of the Douglas-fir seed crop at two of the locations being studied. At the third location, Bloody Camp, only a single larva was found in all the seeds examined. Figures on the damage caused by Megastigmus along with supplementary data are presented on table 10 (appendix).

At the two locations where substantial numbers of Megastigmus larvae were encountered, the bagged cones which were never exposed were free of infestation. The only exception was a single larva in one of the samples from Black Mountain. The cones exposed from April 24 to May 7 at Coopers Ranch were also free of Megastigmus infestation. All of the cone samples exposed from May 7 to June 6 were infested as also were the unbagged cone samples.

In three of the cone samples, few seeds remained after the depredation of Barbara colfaxiana and Dioryctria abietella. Consequently, a reliable estimate of the extent of Megastigmus infestation in these is not possible.

The remaining samples show a remarkable uniformity of Megastigmus infestation. Three of the samples from Coopers Ranch fell between 12.2 and 15.5 percent infested, and two samples from Black Mountain had 43.0 and 43.3 percent of the seed infested. Evidently the exposure period of May 7 to June 6 included most, or all, of the Megastigmus oviposition period. The percent of seeds infested in samples exposed for this period differs only slightly from the percent infested in samples exposed for the entire summer.

The data obtained indicate that a significant portion of the oviposition by M. spermotrophus occurred during the month of May. If we assume that the eggs were randomly distributed among the cones, and if we consider the percent of mature seed infested by Megastigmus larvae to represent the percent of seeds originally infested, it becomes apparent that some seeds which were infested by Megastigmus larvae in May were

eaten by larvae of Barbara colfaxiana and Dioryctria abietella in June and July. It logically follows that where lepidopterous larvae caused drastic reduction in seed yields, they must also have caused drastic reductions in the population of Megastigmus larvae. An estimate of the extent to which the Megastigmus population was reduced was obtained by calculating the average number of seeds per cone destroyed by Megastigmus in the various cone samples. This estimate was obtained by multiplying the number of seeds obtained from a cone sample by the percent of seeds infested and dividing by the number of cones in the sample. The resulting figures are presented in table 11 (appendix). In all instances, the number of seed per cone destroyed by Megastigmus is lower in cones which were exposed the entire summer than in those which were exposed from May 7 to June 6. This relationship holds regardless of the percent of seed infested. Unless seeds containing Megastigmus larvae were destroyed in the course of summer, pairs of cone samples from the same tree should have approximately the same number of seeds per cone infested. There are, in fact, large differences which, for example, suggest that at Coopers Ranch, on tree 2, the Megastigmus population was reduced from 3.5 per cone to 1.3 per cone, a reduction of almost 63 percent. It seems clear, then, that there were some substantial reductions in the Megastigmus population caused by the feeding of lepidopterous larvae. At best, it may be that the lepidopterous larvae are one of the most important factors controlling the level of the Megastigmus population.

Infestation by *Contarinia* sp.

Larvae of Contarinia sp. were present in the cones in small numbers. The data on Contarinia infestations were recorded as the number of seeds in each cone which were damaged by Contarinia larvae (table 11, appendix). The actual number of Contarinia larvae is greater than the number of seed damaged, but is impractical to determine exactly.

Seeds damaged by Contarinia were found only in cones which were never covered. Cones exposed from April 24 to May 7 were completely free of Contarinia larvae. If there was no oviposition after April 24, and the cone buds did not open until April 10, the oviposition period of Contarinia must be completed in less than 2 weeks.

The cones which were infested by Contarinia were heavily infested by Barbara colfaxiana and Dioryctria abietella. Undoubtedly, many seeds which would have been affected by Contarinia larvae were destroyed by the lepidopterous larvae. Therefore, as in the case with Megastigmus, the data on the number of seed destroyed by Contarinia apply only to the seed which escaped destruction by the other insects.

Competition and Comparative Importance

Having tabulated the amount of damage caused by the various species of insects, it is now possible to compare the amount and type of damage caused by each species and to make some judgments as to their relative importance. All of the damage data have been reduced to a common

denominator, the number of seeds destroyed per cone. A table showing the number of seeds per cone destroyed by the various insect species in each sample in the study is presented in table 12 (appendix), which is summarized in table 13.

Table 13.--Comparative amounts of damage caused by various cone and seed insects in Douglas-fir cones, 1959

Treatment	Percent of total seed destroyed by --						: All insects
	: Barbara	: Dioryctria	: Contarinia	: Megastigmus	: Leptoglossus	: insects	
Never exposed	9.7	8.9	0.0	0.0	< 0.1	18.6	
Covered; exposed, recovered	25.3	25.0	0.0	5.5	0.2	56.8	
Never covered	53.2	13.5	5.5	2.0	5.1	79.3	

Reference to the tables shows that Barbara colfaxiana destroyed approximately half of the seed in unprotected cones, or about two-thirds of all the seeds destroyed. From this we may safely conclude that under normal conditions Barbara is the most destructive insect in the cones.

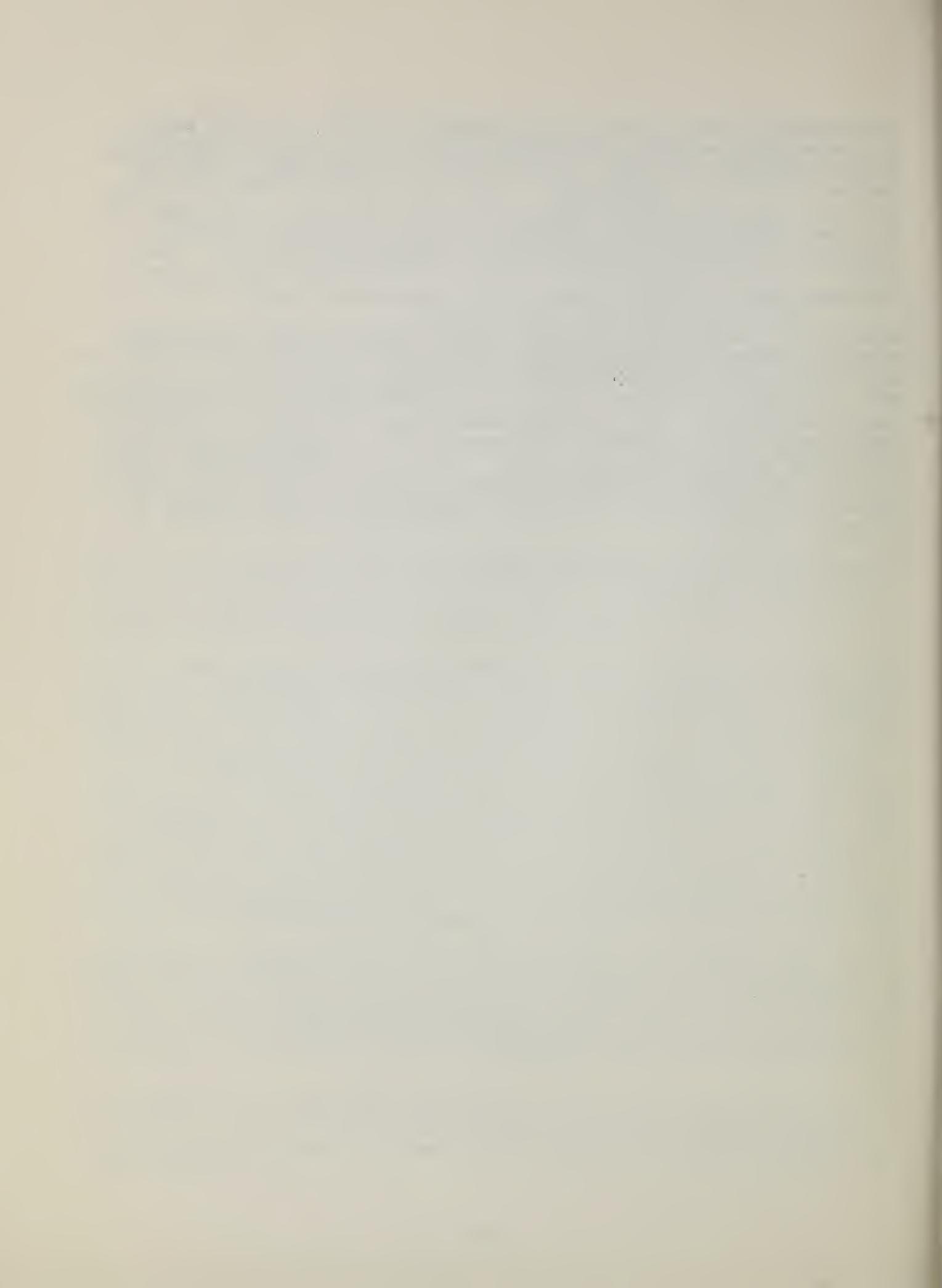
In this study Dioryctria abietella showed clearly its ability to destroy seeds. This was particularly evident in cone samples from which part of the Barbara population was excluded. It is not particularly surprising that the larva of Dioryctria, a large insect with a mining habit, should be rather destructive. However, Dioryctria attacks the cones later than Barbara and the data show an inverse correlation between the amount destroyed by Dioryctria. Because there are only a limited number of seeds in a cone, there are few seeds left for Dioryctria to destroy after the Barbara larvae have mined the cone. The data indicate that a Barbara population of one mature larva per cone would be expected to destroy an average of 18 seeds per cone, which is only slightly less than half of the average seed yield per cone in this study. It would appear that D. abietella is potentially very destructive, and in the absence of competition from B. colfaxiana would be the most serious pest in the cones.

Contarinia sp. caused rather little damage to the cones in this study. The most seriously infested sample lost only 6.3 seeds per cone to Contarinia. In the cones used in this project, Contarinia populations were very low and were further reduced by competition from other insects. There is no hint here of the complete destruction of cones by Contarinia which has been observed at other times.

The amount of seed infested by Megastigmus larvae varied over a wide range. Up to 43.3 percent of the seed was destroyed in severely infested samples. However, the seed samples were made up of seeds which escaped destruction by other insects.

When all of the samples were put on a comparative basis, it became apparent that Megastigmus destroyed considerably less seed than Barbara or Dioryctria. However, the high percentages of seed infested by Megastigmus in the seed samples indicate that Megastigmus is potentially much more destructive than generally recognized in this country. The sharp reductions in the number of seeds per cone destroyed by Megastigmus due to the different treatments illustrate the effect of competition on the Megastigmus population. The absence of severe competition for a period of several years might permit the Megastigmus population to build up to a very serious level.

A portion of the seed examined showed damage similar to that observed when seeds were fed upon by Leptoglossus occidentalis in the laboratory. This type of damage has been tentatively attributed to Leptoglossus and recorded as such. The data are included here to indicate the extent to which Leptoglossus damage was detected. It is entirely possible that light feeding damage by Leptoglossus was not detected. The damage caused by Leptoglossus probably reduces the germinability of the seeds. However, the extent to which this occurs and the amount of feeding necessary to produce a reduction in germinability, if indeed this is an effect of Leptoglossus feeding, remains to be seen.



APPENDIX



Table 8.—*Barbara colfaxiana* infestations in Douglas-fir cones,
cone bagging experiment, 1959

Locality	Tree number:	Exposure period	Cone length		Cones infested:	Pupae/ cone	Apanteles/ cone	Seeds/ cone	Seed yield per cone	Sound seed	Hollow seed	Pct.
			When exposed:	When recovered:								
Coopers Ranch	1	Never exposed			96.0	3.9	0.04	0.0	0.71	678	48.8*	71.5
Coopers Ranch	1	Apr. 24 to May 7	40.9	57.5	99.2	40.0	.44	.0	8.53	428	29.7*	74.5
Coopers Ranch	1	May 7 to June 4	57.5	74.9	85.6	40.0	.43	.0	7.20	144	11.3	56.6
Coopers Ranch	1	Never covered			82.4	83.5	1.02	.37	23.52	47	5.8	10.5
Coopers Ranch	2	Never exposed			90.5	9.1	.09	.0	1.36	330	30.0	55.0
Coopers Ranch	2	May 7 to June 4			91.5	.0	.0	.0	.00	166	20.7	32.5
Coopers Ranch	2	Never covered			86.3	47.8	.43	.09	12.41	82	14.3	5.5
Black Mountain	1	Never exposed			94.1	25.0	.31	.0	6.19	476	34.5*	62.5
Black Mountain	1	May 9 to June 6	55.5	59.4	85.9	78.2	1.19	.0	18.13	103	10.0	32.0
Black Mountain	1	Never covered			74.8	100.0	1.76	.12	34.52	10	.8	73.7
Black Mountain	2	May 9 to June 6	48.4	68.7	61.7	83.9	1.24	.12	18.22	21	2.6	17.9
Black Mountain	2	Never covered			49.5	100.0	1.62	.15	36.00	3	.6	.0
Black Mountain	3	Never exposed			87.0	70.0	1.03	.0	19.18	415	35.7*	61.5
Black Mountain	3	Never covered			71.1	97.0	2.00	.06	34.94	37	5.7	19.3
Bloody Camp	1	Never exposed			97.4	.0	.0	.0	.0	568	37.6	69.0
Bloody Camp	1	May 8 to June 4	40.5	59.5	96.5	.0	.0	.0	.0	407	35.7	59.0
Bloody Camp	1	Never covered			84.8	24.0	.16	.08	4.32	329	27.3	60.5
Bloody Camp	2	Never exposed			79.3	.0	.0	.0	.0	483	42.4*	80.5
Bloody Camp	2	May 8 to June 4	43.2	57.0	79.2	3.1	.03	.0	.64	342	39.0*	47.5
Bloody Camp	2	Never covered			73.7	28.3	.15	.12	6.43	268	30.3*	68.0

* Calculated yield based on mean number of seeds in 4 one gram samples.

Table 9.--*Dioryctria abietella* infestations in Douglas-fir cones,
cone bagging experiment 1959

Locality	Tree number	Exposure period	Cone length			Cones infested	Larvae/ cone	Seeds/ cone	Seed yield per cone	Sound seed	Hollow seed
			When exposed	When recovered	At harvest						
			mm.	mm.	Pct.						
Coopers Ranch	1	Never exposed	96.0	9.8	0.18	1.59	9.00	678	48.78	71.5	26.0
Coopers Ranch	1	Apr. 24 to May 7	57.5	53.5	1.16	11.57	10.02	428	29.66	74.5	24.0
Coopers Ranch	1	May 7 to June 4	74.9	85.6	.88	12.11	13.68	144	11.29	56.6	29.7
Coopers Ranch	1	Never covered	82.4	71.7	.98	12.93	13.15	47	5.83	10.5	33.0
Coopers Ranch	2	Never exposed	90.5	54.5	1.00	7.82	7.82	330	30.00	55.0	39.5
Coopers Ranch	2	May 7 to June 4	91.5	69.5	1.08	14.73	13.68	166	20.7	32.5	34.5
Coopers Ranch	2	Never covered	86.3	52.4	.34	6.27	18.40	82	14.3	5.5	38.0
Black Mountain	1	Never exposed	94.1	18.7	.38	4.50	12.00	476	34.50	62.5	37.0
Black Mountain	1	May 9 to June 6	55.5	59.4	50.0	1.35	10.22	7.55	103	9.97	32.0
Black Mountain	1	Never covered	74.8	28.0	.04	3.48	10	10	.76	73.7	15.8
Black Mountain	2	May 9 to June 6	48.4	68.7	61.7	3.5	.16	1.27	7.83	21	2.57
Black Mountain	2	Never covered	49.5	30.8	30.8	3.38	3.38	3	.62	17.9	63.2
Black Mountain	3	Never exposed	87.0	38.0	.89	6.42	7.18	415	35.69	61.5	38.0
Black Mountain	3	Never covered	71.1	.0	.00	.00	.00	37	5.67	19.3	32.6
Bloody Camp	1	Never exposed	97.4	25.0	.20	2.85	14.25	568	37.65	69.0	31.0
Bloody Camp	1	May 8 to June 4	40.5	59.5	96.5	.0	.00	407	35.76	59.0	38.5
Bloody Camp	1	Never covered	84.8	60.0	.36	6.60	18.33	329	27.3	60.5	17.5
Bloody Camp	2	Never exposed	79.3	20.0	.16	2.83	17.00	483	42.43	80.5	19.0
Bloody Camp	2	May 8 to June 4	43.2	57.0	79.2	21.2	.30	5.61	342	39.03	47.5
Bloody Camp	2	Never covered	73.7	21.6	.70	6.13	8.76	268	30.30	68.0	15.0

Table 10.--*Megastigmus spermotrophus* damage to Douglas-fir cones,
cone bagging experiment 1959

Locality	Tree number	Exposure period	Cone length			Seed yield per cone	Sound seed	Hollow seed	Seeds infested	Seeds/ cone destroyed
			When	When	At harvest					
Coopers Ranch	1	Never exposed				96.0	67.8	71.5	26.0	0.0
Coopers Ranch	1	Apr. 24 to May 7	40.9	57.5	42.8	99.2	29.7	74.5	24.0	0.0
Coopers Ranch	1	May 7 to June 4	57.5	74.9	144	85.6	11.2	56.6	29.7	1.4
Coopers Ranch	1	Never covered				82.4	47	5.8	10.5	0.9
Coopers Ranch	2	Never exposed				90.5	330	30.0	55.0	39.5
Coopers Ranch	2	May 7 to June 4	91.5	166	20.7	32.5	32.5	0.0	0.0	0.0
Coopers Ranch	2	Never covered				86.3	82	14.3	5.5	34.5
Black Mountain	1	Never exposed				94.1	476	34.5	62.5	38.0
Black Mountain	1	May 9 to June 6	55.5	59.4	85.9	103	10.0	32.0	25.0	23.0
Black Mountain	1	Never covered				74.8	10	.8	73.7	1/ 10.5
Black Mountain	2	May 9 to June 6	48.4	68.7	61.7	21	2.6	17.9	63.2	1/ 18.9
Black Mountain	2	Never covered			49.5	3	.6	0.0	37.5	1/ 62.5
Black Mountain	3	Never exposed			87.0	415	35.7	61.5	38.0	0.0
Black Mountain	3	Never covered			71.1	37	5.7	19.3	32.6	43.3
Bloody Camp	1	Never exposed			97.4	568	37.6	69.0	31.0	0.0
Bloody Camp	1	May 8 to June 4	40.5	59.5	96.5	407	35.76	59.0	38.5	0.0
Bloody Camp	1	Never covered			84.8	329	27.3	60.0	17.5	0.0
Bloody Camp	2	Never exposed			79.3	483	42.4	80.5	19.0	0.0
Bloody Camp	2	May 8 to June 4	43.2	57.0	79.2	342	39.0	47.5	52.5	0.0
Bloody Camp	2	Never covered			73.7	268	30.3	68.0	15.0	0.2

1/ These figures are considered unreliable because they are based on samples of fewer than 100 seeds.

Table 11r-*Contarinia* sp. infestations in Douglas-fir cones
cone bagging experiment 1959

Locality	Tree number	Exposure period	Cone length			Cones infested	Destroyed	Seeds /			Seed yield per cone	Sound seed	Hollow seed		
			When exposed	When recovered	At harvest			Cones	cone	Seeds /					
								mm.	mm.	mg. number					
Coopers Ranch	1	Never exposed	40.9	57.5	96.0	0.0	0.0	678	48.78	71.5	26.0				
Coopers Ranch	1	Apr. 24 to May 7	57.5	74.9	99.2	0.0	0.0	428	29.66	74.5	24.0				
Coopers Ranch	1	May 7 to June 4			85.6	0.0	0.0	144	11.29	56.6	29.7				
Coopers Ranch	1	Never covered			82.4	20.0	.48	47	5.83	10.5	33.0				
Coopers Ranch	2	Never exposed			90.5	0.0	0.0	330	30.00	55.0	39.5				
Coopers Ranch	2	May 7 to June 4			91.5	0.0	0.0	166	20.7	32.5	34.5				
Coopers Ranch	2	Never covered			86.3	43.2	1.34	82	14.3	5.5	38.0				
Black Mountain	1	Never exposed			94.1	0.0	0.0	476	34.50	62.5	37.0				
Black Mountain	1	May 9 to June 6			85.9	0.0	0.0	103	9.97	32.0	25.0				
Black Mountain	1	Never covered			74.8	59.4	72.0	6.32	10	.76	73.7	15.8			
Black Mountain	2	May 9 to June 6			68.7	61.7	0.0	21	2.57	17.9	63.2				
Black Mountain	2	Never covered			48.4	49.5	30.8	3	.62	.0	37.5				
Black Mountain	3	Never exposed				87.0	0.0								
Black Mountain	3	Never covered				71.1	63.6	1.70	37	5.67	19.3	32.6			
Bloody Camp	1	Never exposed			97.4	0.0	0.0	568	37.65	69.0	31.0				
Bloody Camp	1	May 8 to June 4			76.5	0.0	0.0	407	35.76	59.0	38.5				
Bloody Camp	1	Never covered			84.8	28.0	1.92	329	27.3	60.5	17.5				
Bloody Camp	2	Never exposed			79.3	0.0	0.0	483	42.43	80.5	19.0				
Bloody Camp	2	May 8 to June 4			79.2	0.0	0.0	342	39.03	47.5	52.5				
Bloody Camp	2	Never covered			73.7	15.0	2.20	268	30.30	68.0	15.0				

Table 12--Comparative amounts of damage caused by various cone and seed insects in Douglas-fir cones, cone bagging experiment 1959

Locality	Tree number	Exposure Period	Exposed:recovered: harvest	Cone length mm.	When At	Number	Seeds per cone destroyed by--			Number	Number	Number	Seeds per Cone			
							All									
							Barbara	Diorcytus	Contarinia							
Coopers Ranch	1	Never exposed		96.0	0.71	1.59	0.00	0.0	0.0	1.22	3.52	34.88	12.68			
Coopers Ranch	1	Apr. 24 to May 7	40.9	57.5	8.53	11.57	.00	.0	.0	.44	20.54	22.10	7.12			
Coopers Ranch	1	May 7 to June 4	57.5	74.9	85.6	7.20	12.11	.00	1.4	.17	20.88	6.39	3.35			
Coopers Ranch	1	Never covered		82.4	23.52	12.93	.48	.9	.9	2.39	40.76	0.61	1.92			
Coopers Ranch	2	Never exposed		90.5	1.36	7.82	.00	.0	.0	3.15	12.33	16.50	11.85			
Coopers Ranch	2	May 7 to June 4		91.5	.00	14.73	.00	3.5	3.10	21.33	6.73	7.14	40.68			
Coopers Ranch	2	Never covered		86.3	12.41	6.27	1.34	.13	.18	21.50	.79	5.43	35.20			
Black Mountain	1	Never exposed		94.1	6.19	4.50	.00	.2	.00	10.89	21.56	12.76	45.21			
Black Mountain	1	May 9 to June 6	55.5	59.4	85.9	18.13	10.22	.00	4.3	.00	32.65	3.19	2.49			
Black Mountain	1	Never covered		74.8	34.52	3.48	6.32	.1	.00	44.42	.56	.12	38.33			
Black Mountain	2	May 9 to June 6	48.4	68.7	61.7	18.22	1.27	.00	.5	.00	19.99	.46	1.62			
Black Mountain	2	Never covered		49.5	36.00	3.38	1.43	.4	.4	.00	41.21	.00	.23			
Black Mountain	3	Never exposed		87.0	19.18	6.42	.00	.0	.18	25.78	21.95	13.56	61.29			
Black Mountain	3	Never covered		71.1	34.94	.00	1.70	2.5	.93	40.07	1.09	1.85	43.01			
Bloody Camp	1	Never exposed		97.4	.00	2.85	.00	.0	.00	2.85	25.98	11.67	40.50			
Bloody Camp	1	May 8 to June 4	40.5	59.5	96.5	.00	.00	.0	.40	.40	21.45	13.73	35.58			
Bloody Camp	1	Never covered		84.8	4.32	6.60	1.92	.0	.00	6.00	18.84	16.52	4.78			
Bloody Camp	2	Never exposed		79.3	.00	2.83	.00	.0	.21	3.04	34.16	8.06	45.26			
Bloody Camp	2	May 8 to June 4	43.2	57.0	79.2	.64	5.61	.00	.0	.00	6.25	18.54	20.49			
Bloody Camp	2	Never covered		73.7	6.43	6.13	2.20	.2	.2	5.00	19.96	20.60	4.54			

